how it works

FIBER-OPTIC-BASED GYROSCOPES CAN PROVIDE GOOD ACCURACY AT MODEST COST USING CENTURY-OLD PRINCIPLES.

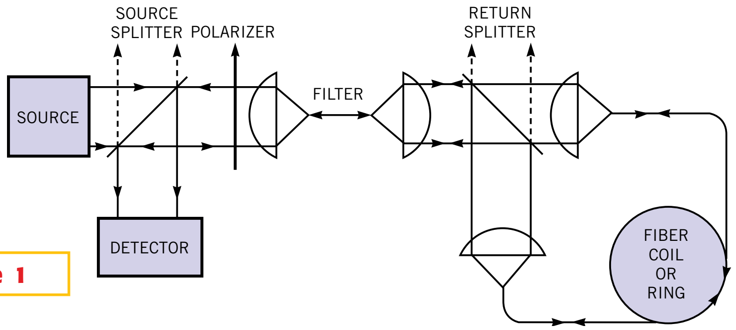
Optics, electronics merge to provide a sense of where you are

By Bill Schweber, Executive Editor

MOST ENGINEERS ARE FAMILIAR with the mechanical gyroscope, which you can use either to maintain a fixed heading as a gyrocompass or to provide inertial navigation information when you combine it with accelerometers. Although the gyro is a mechanical device and thus subject to wear and drift, designers have refined it over the last 60 years so that a gyro-based navigation system can provide extraordinary accuracy and reasonable reliability (**Reference 1**). Further, unlike mostly mechanical gyro systems of the 1940s and 1950s, today's gyro-navigation units use sophisticated real-time algorithms to compensate for known errors and drifts, as well as to implement statistical models of sources of errors.

But you're wrong if you think that the gyroscope function for navigation is now obsolete due to the availability of satellite-based navigation and low-cost GPS chip sets. GPS has several major drawbacks. For example, it doesn't work in tunnels, in underground oil and gas wells, in submersible research vehicles, or outside the low orbit of the GPS satellites. Further, inadvertent interference and deliberate spoofing can corrupt the signal, and the time to deliver an initial valid position readout is approximately a minute. For these and other reasons, GPS alone is unsuitable for many applications. However, the combination of a gyro and GPS can provide an accurate and reliable relative-motion system that tells you how much you have moved and is useful for remote-operated vehicles, submersibles, and tunnel exploration. This combination is also useful for an absolute-motion navigation-grade system that tells you exactly where you are, such as those that missile and satellite guidance need.

Figure 1



Though the Sagnac principle of optical sensing of rotation is simple to describe at a first level, a basic setup requires numerous optical signal components.

Yet the established mechanical gyro is meeting its match from several sources. One approach uses MEMS (microelectrical-mechanical-system) structures to provide the moving-element functions but on a much smaller mechanical scale and with new techniques to overcome traditional error sources. Long-established gyro experts, such as The Charles Stark Draper Laboratories (www.draper.com), are exploring this approach. Another successful technique uses laser-sourced beams of light passed around a ring or an optical fiber, with interference patterns indicating any rotation of the gyro platform. These optical gyros are now available from many sources, such as KVH Industries (www.kvh.com), Sperry Marine (www.sperry-marine.com), and Honeywell (www.ais.honeywell.com).

Physicist Francis Harress in 1911 first observed the principle in the optical gyro, and physicist Georges Sagnac in 1913 also observed it. Literature now refers to it as the Sagnac Effect. This effect is an outgrowth of the work of physicist Albert Michelson and chemist Edward Morley, who won the Nobel Prize in 1907. Their 1881 interferometry experiment demonstrated that the Earth does not travel through any ether, and this experiment foreshadowed Albert Einstein's radical assumption on the constancy of the speed of light regardless of any motion of the light source or observer.

Figure 2

The DSP-5000 from KVH comes in a strap-down, compact box and includes a single-axis FOG along with processor-based electronics, which provide real-time correction.

In the Sagnac demonstration, a polarized beam of light splits into two beams, and the beams move in opposite directions through a ring path—usually, triangular or square with mirrors at the corners—or an optical fiber. After their counterrotating trips around the ring or fiber, the beams emerge and interfere with each other. If the unit does not rotate, the beams travel the same distance and thus cancel each other out when they emerge. However, if the unit rotates while the beams are passing through, one beam travels a shorter distance, and the other travels a longer distance, due to relativistic effects. The differing travel times produce a shift in the interference pattern, which an optical detector can sense. A complete optical gyro requires other components, as well (**Figure 1**). You can find more detailed explanations of the Sagnac Effect, actual implementations, and underlying equations in **references 2**, **3**, **4**, and **5**.

Although the understanding of the Sagnac Effect depends on relativity theory, the actual setup appears fairly straightforward. Don't assume, though, that building a practical optical gryo should also be straightforward. Although demonstrating the principle doesn't require even a laser as a light source, building a reasonably accurate gyro involves understanding and minimizing many of the sources of error and signal contamination, just as with any precision instrumentation. Until the 1980s, when optical gyros found use in commercial aircraft, such as the Boeing 777, they were too imprecise and nonrepeatable for basic, moderate-accuracy applications.

In the first optical gyros, RLG (ring-laser-gyro) designs, the light beam travels through an evacuated path acting as a waveguide; high-reflectance mirrors are precisely mounted at the corners of the RLG square or triangle. The RLG path can be a few meters long; higher precision applications require paths of tens of meters, but these paths are impractical for most uses.

FOG GETS YOU OUT OF THE FOG

As optical fiber technology improved, IFOGs (interferometric fiber-optic gyros), commonly called FOGs, have become practical alternatives. In this design, the light path is not a hollow-light waveguide but an optical fiber. One advantage of this approach is that it requires no corner mirrors, which mandate precise and rugged mounts. Another advantage is that you can build the light path as a compact, coiled fiber tens of meters long, which holds the potential for greater accuracy and improved low-rate-resolution performance.

The RLG design and, to a greater extent, the FOG design, offers many practical and cost advantages over mechanical gyros. One advantage of these newer designs is that you can strap them down to vehicles because they have no internal gimbals. As with other technological advances, the principle may be relatively simple, but a precise application means identifying and then eliminating or compensating for first- and second-order error sources. For example, a light-source laser must have both short- and long-term stability in its wavelength and its output power. Note that an RLG requires a more powerful light source than does an FOG because, in an RLG, the light source does not move down a thin fiber.

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Any temperature change causes changes in an RLG's optical path length and thus the light wave's phase. In one precision implementation of the RLG, the device measures the relatively low rate of the earth's rotation and bores it into a block of glass-ceramic material having a near-zero temperature coefficient of expansion (**Reference 6**). The light path in the RLG must be a high vacuum, so that air or other molecules don't interfere with the light waves. The beams, which should be independent as they travel past each other, can sometimes lock in and synchronize with each other at low angular rotation rates due to interbeam crosstalk that arises when the corner mirrors are less than perfect and scatter some of the incident light. The designers of the implementation minimized the problem by using multilayer dielectric mirrors with 99.9999% power reflection.

The FOG has subtleties of its own. For example, any strain on the fiber and how it is supported or wound causes phase shifts, signal dispersion, or polarization changes, which translate into errors that can swamp the desired result (**Reference 7**). FOG manufacturer KVH Industries makes its own fiber with an elliptical cross-section, rather than the standard, widely available communications fiber, because the elliptical shape counteracts some polarization issues. The sensitivity of the FOG depends on both fiber length and diameter: Longer, thinner fiber provides a better rotation rate—but at the cost of other potential trade-offs—than shorter, wider fiber.

Nongimbaled, strap-down FOGs—especially when you combine them with a GPS system and even accelerometers to sense linear-axis motion—offer many potential advantages over gimbaled, mechanical gyros. Processor-based computational algorithms can compensate for many errors and also integrate motion data from other position and motion sources to provide an easy-to-use, calculated, highly accurate output. A compact single-axis FOG, such as the KVH DSP-5000, costs approximately $4000, provides output-scale-factor accuracy of 0.05%, and is usable at angular rates as fast as 500°/sec or as low as tens of degrees per second (**Figure 2**).□

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REFERENCES

All references are on the Web version of this article at www.ednmag.com.